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FOREIGN TECHNOLOGY DIVISION

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GLASS FIBER USED IN LIGHT COMMUNICATIONS

by Chinese Academy of Science's
Shanghai Silicate Institute
No. 3 Light Fiber Group

1. Preface

The appearance of laser technology has promoted the development of visible light waves in the field of electromagnetic waves. Because several quantity levels of the basic frequency of light are high, thus its frequency band is broad. Theoretically, it can simultaneously transmit 10 million television programs or 10 billion telephone lines. Furthermore, laser light beams are very narrow and their security and anti-interference power is strong. Therefore, the utilization of the laser as a carrier wave to establish laser communications networks has been an important international problem, that is, how to apply research to develop laser technology. But the results of experiments have shown that laser atmospheric transmission has been seriously limited by scattering caused by atmospheric particles such as dust, fog,

dew, snow and rain, and interference by clouds and turbulence. Light wave guide communications is excellent for offering a transmission path which is non-suseptible to atmosperic interference.

To realize long distance light transmission people have carried out research on dielectric film wave guide and lens wave guide. Much work has been done on lens wave guide but it is still far from being applicable. Up to the 1970's, light guiding fibers, semiconductor lasers and integrated optics have had great breakthroughs especially in the continual decrease of light guiding fiber transmission loss which has basically changed the face of light communications research. Table 1 shows the development of research on light guiding fiber.

Table 1 The Development of Research on Light Guiding Fiber

Time (years)	Attenuation Value (decibel/kilometer)
1960	1,000
1970	20
1972	4
1974	1.2
1975	0.85

This paper focuses on introducing low loss light guiding fiber technology and takes quartz glass as an example for explanation.

2. The General Situation

Light guiding fibers are composed of a high refraction power translucent optical glass as the core and a surrounding thin layer of low refraction power glass. Its diameter is several millimeters to several hundred millimeters. Several typical light guiding fibers are shown in chart 1.

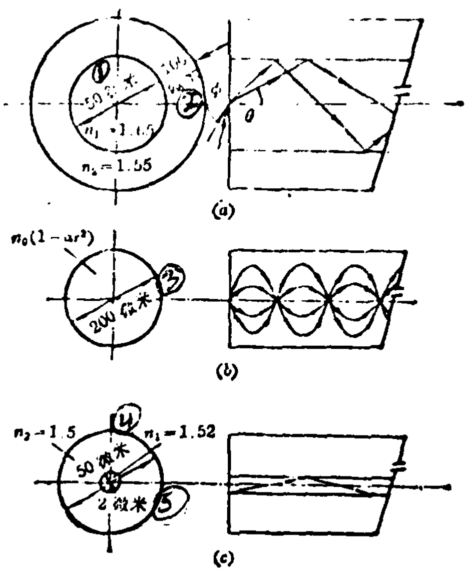

图1 典型的纤维结构
(a) 多模 (b) 自聚焦 (c) 单模

Chart 1 Typical Fiber Structures

(a) multimode
(b) self focusing
(c) single mode

1. 50 micron
2. 100 micron
3. 200 micron

4. 50 micron
5. 2 micron

After light enters one end of the light guiding fiber, it goes through the multiple reflection (sleeve layer mode) on the core-sleeve layer surface or the refraction in the core (self focusing mode) and is transmitted to the other end. When there is a sleeve layer outside the fiber formed beam or light cable, it can prevent escaping action between each of the fibers.

In the last few years, there have been major advances in the preparation of low loss light guiding fiber (see table 1). We can see that the amount of attenuation is equal to or is lower than the level of existing coaxial cable or millimeter wave guide. Therefore the use of glass fiber as a substance for light communications transmission is practical. Light guiding fiber, aside from being able to transmit 30 billion units/second information high frequency band in unit time, also has the special feature of anti-electromagnetic interference, small measurement, light weight, dielectric insulation and endurance to radiation. Light guiding fiber is light and pliable, their turning radius is small, they are convenient to lay and they possess good temperature stability. The cost for installing a glass fiber system is lower than that of coaxial cable and micron wave systems. Moreover, following the rising of information speed, cost will decline much

faster than the coaxial cable and micron wave systems.

The light guiding fiber communications system can be used to link buildings or inner city telephones as well as for phonovision systems, communications televisions and data transmission equipment; for a several kilometer main line with low or middle level capacity channels; and for middle level and high capacity light transmission between distant cities. Besides this, the use of light guiding fibers can be extended to situations that demand light or information transmission substances with small energy loss and a very high degree of curve such as in a high capacity central network or high capacity computer communications or transmission, joined scanning laser radar systems or radar systems and light transmission of various laser treatment machines used in medicine.

We can see from table 2 that fiber light communications have many advantageous features.

Table 2 Comparison of Coaxial Cable and Laser Light Cable

Quality of Substance	Coaxial Cable	Laser Light Cable	Note
Diameter (microns)	9.5	0.05-0.3	
Bending radius (microns)	> 50	>5-10	
Attenuation (decibels/ kilometers)	19 (60 megacycles)	2-8	Lowest has reached 0.85 dec/kilo

Repeater distance (kilometers)	1.5 (60 megacycles)	5	Already has distance of 20 kilometers
Capacity/unit section	1	100-10,000	
Weight/unit capacity	1	1/5-1/100	

3. Basic Properties of Fibers

A. Types of Fibers

At present, there are basically two different types of cylindrical fibers. One type is the refracting power step type change fiber which has a fixed refracting power core and a lower refracting power sleeve layer. The other type is the refracting power gradient type change fiber. Its axis center has a higher refracting power and the four sides continually decrease according to the parabolic pattern.

The refracting power changes of the second type of fiber are shown in Chart 2.

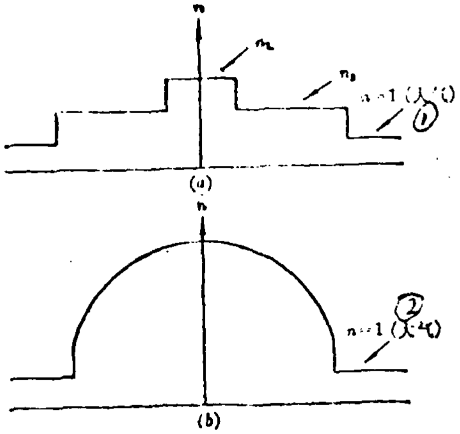

图2 光导纤维的折射率分布
(a) 套层型纤维 (b) 自聚焦型纤维

Chart 2 Refracting Power Distribution of Light Guiding Fibers

(a) Sleeve layer fiber
(b) Self focusing fiber
1. Atmosphere
2. Atmosphere

The parameter below can be used to show the refracting power step type change cylindrical wave guide:

(1) $$V = \frac{2\sqrt{2}\pi r}{\lambda}(\bar{n}\cdot\Delta n)^{1/2}$$

In the formula: r is the core radius of the wave guide, λ is the wave length of the free space, $\bar{n}$ is the mean refracting power of the core and sleeve layer; Δn is the refracting power

difference of the core and sleeve layer.

When $V < 2.4$, the fiber is single mode broadcast and is indicated by HE_{11}. Because the fiber has axial symmetry, the mode has polarized simple combination. The chief advantages of the single mode wave guide are that the frequency band is wide, it is three quantity levels greater than multimode wave guides and it can be used in high capacity systems.

When $V > 2.4$, the broadcast mode quantity follows the increases in the size and speed of the value of V. This can be indicated approximately as:

(2) $$N - \frac{1}{2} V^2$$

If there is multimode broadcasting, each mode uses slightly different speeds. Short pulses are split into a series of pulses and at different times reach the far end of the wave guide. The differences in arrival times are shown by the following formula:

(3) $$\Delta t = \frac{L}{C} (n_1 - n_2)$$

In the formula: L is the length of the fiber and C is the broadcasting speed of the light in a vacuum.

As regards the $n_1 = 1.52$, $n = 1.50, \frac{n_1}{n_2} = 1.01$ fiber, if L is 1 kilometer, the fastest and slowest time difference of the mode reaching the far end is 50 millimicroseconds and the information broadcasting speed is 33 megaunits/second. When L is even longer, broadcasting speed decreases. On the whole, we can see that the Δt value is the measured pulse width and the pulse width of the multimode wave guide follows the linear increases of the fiber's length. With the expansion of the single mode wave guide pulse we cannot use the above formula as its information distortion is determined by the scattering and light source frequency spectrum width of the fiber material. Yet, when the band width is very small, these effects are much smaller than multimode chromatic dispersion. As regards the luminescent diode which has a frequency band width close to 40 millimicroseconds, the narrow pulse width is extended about 4 millimicroseconds/kilometer, the gallium arsenide emptying into the laser is extended about 0.1 millimicroseconds/kilometer and the neodymium yttrium aluminum garnet laser is then 0.01 millimicroseconds/kilometer. When the information broadcasting speed of the single mode fiber is used in a coherent light source it can reach to 10^{11} megaunits/second which is already close to the theoretical maximum value.

For the refracting power continuously changing wave guide

(gradient type wave guide), its formula for refracting power changes is:

(4) $n = n_0 \operatorname{sech} p \cdot r$

In the formula: n_0 is the refracting power of the fiber axis and p is the radial change constant of the focal distance.

In this type of self focusing type fiber, if the fiber is sufficiently fine or causes the p to be sufficiently small, it will also be able to form single mode fibers. When comparing the multimode self focusing wave guide and relatively simple multimode sleeve layer type wave guide, its primary advantage is that its information transmission distortion is very small. Because of this, it is able to transmit phase information. When the pulse is transmitted to the end of a fiber of length L, the width is close to:

(5) $\Delta t = \frac{L}{2C} n_0 p^2$

For convenience of comparison, we took $n_0 = 1.5$ and $p = 0.1$ which corresponds to the above mentioned $\frac{n_1}{n_2} = 1.01$ refracting power step type change wave guide. Its pulse is extended to Δt at which time it is only 0.25 millimicroseconds and the above seen corresponding step type wave guide is 50 millimicroseconds. In

considering the information distortion angle, the refracting power parabolic change fiber is naturally superior.

B. Fiber Loss

Attenuation of glass material includes absorption and scattering. There are three main types of absorption: eigen, impurity ion and atom defect color center. There are also three types of scattering: eigen, glass homogeneity and radial aberration in refracting power.

Eigen absorption is a materially "ideal" state of absorption. Generally, glass is an insulating medium material and its electron energy band is very wide. Therefore, in the visible light range of a spectrum it is completely transluscent. This is correct for the great majority of applications yet because the light wave guide demands a material absorption coefficient three quantity levels less than the common one, there must be even more accurate determination.

Impurity absorption is essential because the transitional electrons of such materials as iron, cobalt, chromium, nickel or copper in wide glass electron energy levels lead in additional electron energy levels so that absorption light quantum is elicited. The absorption of these ions are different because in

different glass there are changes in their atomicity. Because their absorption peak is very wide, it is difficult to use the relationships of the fiber absorption spectrum to determine the value. Assuming that absorption has a linear relation with concentration, then we can derive an absorption value when concentration is low. Research on the absorption peak of each type of ion in quartz glass has shown that if we want to attain absorption lower than 20 decibels/kilometer attenuation, the concentration of impure ions must be lower than several per 100 trillion (-10^9). Table 3 is measured data in a wave length of 800 millimicrometers. Because of this, the glass purity of light guiding fibers corresponds to the semiconductor purity requirements of the electronic device.

Table 3 Allowable Existing Impurity Ion Concentration (800 Millimicrometers) In Quartz Glass With Attenuation Lower Than 20 Decibels/Kilometer

Ion Type	Fe	Mn	Ni*	Cu*	Cr	V	Co*
Allowable content ($\times 10^{-9}$)	425	833	712	2140	33	19	816

* In some glass systems, Ni is 20-26, Cu is 9-50 and Co is 2.

There is still another important impurity which uses the existing "water" of the OH^- ion form. In an area of 0.725 and

0.950 microns, there are very easily differentiated distinct absorption peaks. They are respectively the basic vibration frequency's third and fourth harmonic of the vacuum wavelength 2.8 micron hydroxyl. In quartz glass, the absorption of water in a 0.950 micron wave band elicites attenuation of 1.25 decibels/10^{-6} kilometer weight. It is different from the absorption of transitional metal ions and the water absorption does not change in accordance with the different types of glass.

The third source of absorption is the atom defects in the glass structure. Using radiation to study oxygen defects in quartz glass, it was shown that the situation seemed to be similar to melting under oxidixed conditions of the elicited color center in the glass. It was observed that the ion oxidized state is very important for glass fiber attenuation.

Because of this, foremost in absorption is the elicited attenuation of the transitional metal ions and water.

Glass molecules have no order of distribution, but have heat causing irregular fluctuation in refracting power and irregular fluctuations in the concentration of oxide components in the glass all of which can cause scattering. The scattering caused by the molecule's abscence of order of distribution is called Rayleigh

scattering and it forms an inverse ratio to the fourth power with the wavelength. Because of this, it follows the decrease of the wavelength and increases very quickly. This is the minimum attenuation of glass material and therefore only in the visible light range and infrared range of relatively long wavelengths can very small attenuation be attained. The Rayleigh scattering attenuation of quartz glass outside the 1 micron wavelength is 0.8 decibels/kilometer. This is the maximum value and it cannot make any further notable drop.

The other heterogenous properties of glass such as the split phase tendency of some components or incorrect mixture when melting causing the production of changes in refracting power, can all cause radiation. However, when compared to the above mentioned microscopic heat irregular fluctuations, these heterogenous properties are technological problems and means can be devised to avoid them.

The third reason for scattering is the deviation of the radial refracting power. In the refracting power gradient type continually changing wave guide, this kind of scattering has no means of being distinguished from the other elicited heterogenous scattering. In the refracting power step type non-continuous changing wave guide, this type of scattering is caused by the

coarseness of the core sleeve layer surface.

The chromatic dispersion of glass is quite important. Its limiting of the frequency band width causes the pulse in the wave guide to expand broadcasting time resulting in the limitation of the pulse speed rate and information flux. Generally, the frequency band width of the single mode wave guide is limited by the material's chromatic dispersion and multimode wave guides are limited by the mode's speed distribution.

From the above discussion, we can say that foremost we should select a wave system from a material of lower attenuation and expanded pulse.

4. The Glass System

We should first select those systems that can use suitable melting to manufacture optical homogeneous glass systems. The manufactured glass should not have any trace split phase or that can cause the slightest uneven light scattering areas. At the same time, because the potential quantity needs for the entire communications system are great, we should also use an abundant amount of elements from the natural environment. At present, international focus is on research on three composite systems: quartz glass, soda-lime glass and lead-silicate glass. All of them

are relatively mature systems and all are able to satisfy these requirements.

In the major wavelength ranges, glass eigen absorption is very low and quartz glass is the lowest. Glass with a commonly higher refracting power has greater absorption. Because the refracting power of quartz glass is very low, most do not have even lower refracting power glass for making the outside and so use mixed quartz glass for the core so that the quartz glass makes a sleeve layer. Fluorine plastic can also be used for the sleeve layer so that the quartz glass for the core forms quartz glass fiber. Possibly the use of the chemical vapour deposition method can make low refracting glass for the manufacture of a quartz glass core sleeve layer.

The transitional metal ion in the glass is elicited by the raw material and fiber for manufacture in the technological process. Because of this, the decrease in the amount of the oxidized component in the glass can lower the chance of eliciting impurities.

The diffusion effect has a great influence on the fiber's radial refracting power distribution. For the refracting power changing gradient type fibers, every effort is made for the

diffusion effect to be as large as possible and the diffusion effect of the refracting power step type changing fiber should be limited. In order to accomplish this, later researchers should as far as possible avoid one valence ions such as alkaline metal thallium and cuprous. Because the migration rate of ions usually forms an inverse ratio with their valence number, the former then depends on the diffusion of these ions. One valence thallium ions have the greatest relative effect on the refracting power and the refracting power of common thallium bearing glass is about 1.8. After potassium ion exchange, the smallest refracting power is about 1.5. Besides this, there are also various types of ion combinations. After the fiber goes through ion exchange, the refracting power in the axis section is the largest, is smallest on the outside circumference and there is parabolic distribution.

When selecting a glass form, one must also consider machine strength or else the fiber will be too fragile and break easily. Quartz glass is most endurable to corrosion and its strength is also relatively high.

5. Manufacturing Technology

A. Glass Melting

Because the demands of light guiding fibers for purity are

high, we should, as far as possible, simplify the technological process so as to prevent contamination. When the fibers melt not only do the raw materials need to be pure but the crucible also has corresponding requirements. Because high temperature melting can corrode the crucible, this can influence the components and purity. We think that with the use of single component quartz glass, it is easy to raise the purity of the raw materials so as to decrease the chance of eliciting impurities. The formed light guiding fibers can transmit ultra-violet area, visible light area and near infrared area rays. This is especially true for the wider applicable wave bands of the hydroxyl bearing very low super pure anhydrous quartz glass guiding fibers. Yet, its melting temperature is very high (near 2,000° C) and in this way it is difficult to select a suitable crucible and heating component. For this, we can use the new technique of high frequency induction plasma flame high temperature as a method for melting without using a crucible. Using high purity silicon tetrachloride as the raw material, super pure anhydrous quartz glass is formed directly from the vapour phase and reaches a very high optical homogeneity.

When the temperature of the high frequency induction plasma flame is very high, the nucleus temperature can reach 15,000K, the mean temperature is 4,000 to 5,000K and the temperature gradient is very large. Because there is no electrode contamination, the

flame is pure and we can arbitrarily select working atmosphere airflow warmth and smaller noise which is a relatively ideal high temperature method. By using quartz glass tubing for the lamp, inserting high frequency in the coil and passing argon vapour or air into the lamp, they receive high frequency electromagnetic excitation and a plasma flame is produced. Its simple structure is shown in chart 3.

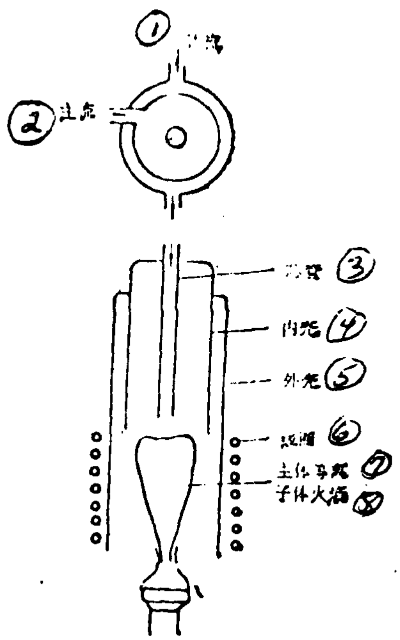

图3 等离子体火焰示意图

Chart 3 Schematic Diagram of the Plasma Flame

1. Side flow
2. Main flow
3. Core tube
4. Inner shell
5. Outer shell
6. Coil

7. Main plasma
8. Plasma flame

The thin central core tube can pass into the powder material or silicon tetrachloride and enter the plasma flame. The lower end uses quartz glass tube support material to hold the formed quartz glass. If when we use crystal powder as the raw material, the growth speed of the melted quartz glass base is too fast, then the quality of the glass will depend on heating homogeneity. If the airflow of the saturated silicon tetrachloride vapour follows the core circulation passed the core tube and enters the plasma flame, in a high temperature flame, there will be produced the following reaction:

$$SiCl_4 + O_2 \longrightarrow SiO_2 + 2Cl_2$$

Chart 4 shows the general situation of high frequency plasma flame melted super pure anhydrous glass. When silicon tetrachloride is used, the growth speed of quartz glass is slower than that of the powder material and is usually 2-7 microns/hour. To raise the purity of the glass, it is necessary to raise the purity of the silicon tetrachloride and the gas used for operation as well as maintain a clean environment. This new high temperature technique can also be used to melt component glass in other systems. Yet, it is necessary that material for each oxide component be homogeneously

mixed. When melting, the temperature on the surface of the material must be kept constant so as to avoid the production of bubbles in the glass.

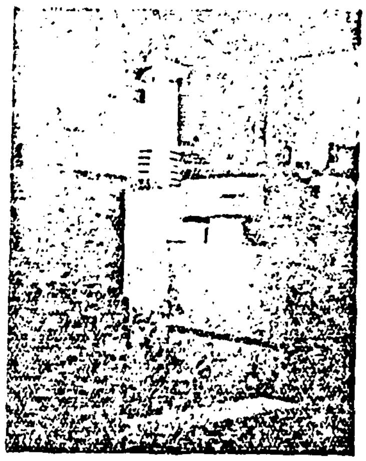

图4 高频等离子体火焰熔制超纯无水石英玻璃

Chart 4 High Frequency Plasma Flame Melting Super Pure Anhydrous Quartz Glass

The manufacturing technology for the refracting power non-continuous multimode wave guide is much simpler than that of the single mode wave guide. In the last several years, many techniques have already been used to produce light guiding fibers. There are two commonly used techniques called "the double crucible method" (see chart 5) and "the tube-rod method" (see chart 6).

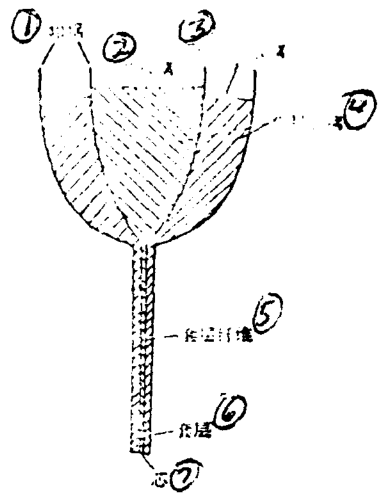

图5 双坩埚法拉丝

Chart 5 Double Crucible Method Wiredrawing

1. Crucible
2. Core glass
3. Outer crucible glass
4. Melted glass
5. Sleeve layer fiber
6. Sleeve layer
7. Core

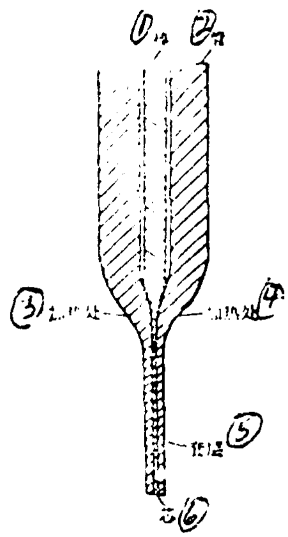

图6 管棒法拉丝

Chart 6 Tube Rod Method Wiredrawing

1. Rod
2. Tube
3. Heating area
4. Heating area
5. Sleeve layer
6. Core

"The double crucible method" maintains melted glass in two concentric crucibles. The inner crucible container is used to make the core glass material, the outer crucible container is used for the sleeve layer's glass material and they are concentrically placed in the two crucible openings. As a result, when the glass flows, it has already become light guiding fiber. One advantage

of this is that compared to the permitted wider selection, the radius of the core-sleeve layer can draw two types of light guiding fiber suitable for single mode and multimode transmission. "The tube rod method" uses a concentric glass tube and a glass rod in an electric furnace or uses gas blowtorch heating. Under high temperatures, there is drawn necking, there is maintained a sectional geometrical shape and the drawn fibers are coiled on the lower end around the drum. The diameter of the fiber as related to the speed of the delivery of materials, drawing speed and temperature and the ratio of the tube rod outer diameter is maintained in the fiber. The drawback of this method is that the processing demands for the inner and outer surfaces are high and if there are drawbacks there there can be irregularities and scattering loss produced on the fiber's core-sleeve layer surface.

Depending on the surface tension, cylindrical fibers are relatively easy to make and if the fiber demands a right angle edge section, when drawing, it must quickly pass through the heating area so as to avoid greater surface tension and changes in form. Seriously speaking, after drawing, it can be slightly circular.

Because the core is very small, the measurement of the single mode wave guide's core sleeve layer is larger and

manufacturing technology is more difficult to control. Formula (1) indicates that because the V value needs to be maintained at about 2, if radius r is increased, Δ n will necessarily decrease. However, controlling the Δ n value to about 5 x 10^{-3} is obviously very difficult. For example, in (c) shown in chart 1, if $n_2 \sim 1.5$ and the operating wavelength is 800 millimicrometers and V=20, then it is necessary that $r \cong 2$ microns, the sleeve layer be 50 microns and the ratio of the core and sleeve layer be 25:1.

We can see from chart 7 that the difference in relative measurements of the multimode and single mode light wave guide core sleeve layers is large. In chart 7, (a) is the "tube rod method" which uses a fixed measurement tube rod base material to draw and make a sleeve layer type multimode light wave guide. When the single mode is made, if we use a 2 millimeter rod, then we need a 50 millimeter tube for the base material and construction is troublesome. Although we can use a divided several step method to resolve this, it is after all not convenient. The use of a new type of technique as shown in chart 7's (b), the chemical vapour phase precipitation method, is convenient. The various high purity gases of synthetically fixed refracting power substances that pass into the glass tube such as $SiCl_4$ and BCl_3 and the oxyhydrogen flame heating onthe outer part under rotating conditions, will then deposit a thin glass type coating on the inner wall of the glass.

The whole tube is again heated and then in the middle is formed a fine core. After drawing, there is formed a single mode light wave guide. At present, the chemical vapour phase precipitation method is not only able to make single mode fiber but it can also make multimode fiber.

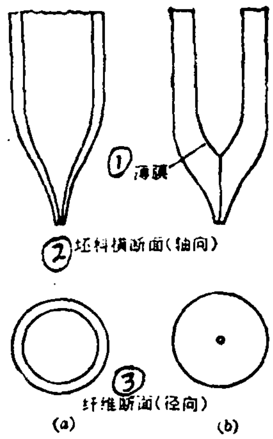

图7　多模和单模光波导的制造工艺

(a)典型的多模制造工艺，简称"管棒法"。(b)用以制造单模的薄膜坯料的技术，此模能以简单的工艺制成非常小的芯。

Chart 7 Manufacturing Technique For the Multimode and Single Mode Light Wave Guide

(a) The typical multimode manufacturing technique is called "the tube rod method".
(b) Technique of using a thin coating base material for the manufacture of a single mode. This mode can use a simple technique to make a very small core.

1. Thin coating
2. Cross section (axial) of base material
3. Fiber sections (radial)

We first made a type of externally arranged fluorine plastic quartz glass multimode light guiding fiber. At first, we melted a super pure anhydrous quartz glass base material with a high

frequency plasma flame and after cutting and grinding made a circular rod. In our self designed and self manufactured wiredrawing machine, we drew fiber and the wiredrawing speed was continuously regulated. The machine was equipped with a high temperature heat generating furnace and furnace temperature reached 1900°C. The wiredrawing device is shown in chart 8.

图8 纤维的拉制装置

Chart 8 Fiber Drawing Device

The circular rod inserted in the top of the material transfer bar automatically passes the high temperature area at a fixed speed and draws the fiber at a suitable speed to coil on the bottom end drum. After it arrives at a determined length it stops

automatically. To maintain cleanliness, in the operation process, because of the manufactured quartz glass fiber, it is best to fill the container with clean glass for protection so that before the next step there is spread on the surface fluorine bearing plastic. Then the surface will not be contaminated. After the spreading of fluorine bearing plastic, there are then produced refracting power non-continuous super pure anhydrous quartz glass multimode light guiding fibers.

To attain lower fiber attenuation, it is also necessary to equally lower the attenuation of the sleeve layer glass. For example, when the transmission modes of a 4 decibel/kilometer wave guide (V-55) receive excitation, the sleeve layer glass loss must be smaller than 80 decibels/kilometer.

A device with a determined light guiding fiber loss (including absorption and scattering) is shown in chart 9.

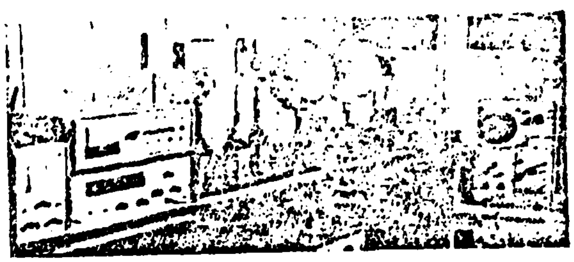

图9 光导纤维总衰减的测定装置

Chart 9 Light Guiding Fiber Total Attenuation Determined Device

We used the direct flow measurement method to measure the total attenuation of the fiber. In the entire measurement process, to gaurantee the accuracy, dependability and duplication of the data, we not only demanded that the components in the device have excellent stability and precision but also required the maintenance of cleanliness. In operation, this caused the measured fiber or sample surface not to receive the contamination of dust and other particles, and for the fibers not yet laid out special attention was given to surface cleanliness.

The attenuation value (determined device shown in chart 10) of the glass piece and the quantitative changes in the attenuation value of the light guiding fiber can guide our selection of effective manufacturing technological measures. We can use an absolute method to determine the absorption attenuation of a quartz glass sample.

图 10 玻璃块样吸收衰减的测定装置

Chart 10 Glass Sample Absorption Attenuation Determined Device

Qualities such as being able to advance precision in determining the wave spectrum curve, pulse expansion, mode type transmission and fiber-light source coupling of light guiding fiber loss will be able to be even more advantageous for raising fiber quality and promoting the quick development of work.

6. Conclusion

The advancement of research on the use of fiber in light communications has been very fast and has given impetous to its being used in the development of electronic devices such as microsemiconductor lasers, luminous diode tubes, avalanche diode tubes, light modulators and light detectors.

In the last few years, although China has established a certain basis in the areas of glass fiber manufacture and electron devices, yet this work has thrown the field into very broad uses. Because of this, it is necessary, under the unified leadership of the party, to select a great cooperative method to adapt to China's socialist revolution, the demands of building and developing socialism and to even faster develop China's communications work.